

APPLICATION
FOR
UNITED STATES LETTERS PATENT

PATENT APPLICATION

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

Be it known that Daryoosh Vakhshoori of 10 Rogers Street, Apartment 205, Cambridge, MA 02142 and Min Jiang of 3 Breezy Point Road, Acton, MA 01720 have invented certain improvements in EFFICIENT FIBER-SEMICONDUCTOR TUNABLE LASER SOURCE of which the following description is a specification.

JES/CORE70.CVR

EFFICIENT FIBER-SEMICONDUCTOR TUNABLE LASER SOURCE

Reference to Pending Prior Patent Application

5 This patent application claims benefit of pending
prior U.S. Provisional Patent Application Serial No.
60/220,070, filed 07/21/00 by Daryoosh Vakhshoori et
al. for Efficient Fiber-Semiconductor Tunable Laser
Source, which patent application is hereby
incorporated herein by reference.

Field Of The Invention

10 This invention relates to tunable laser sources
and more particularly to laser sources comprising
optically pumped tunable vertical cavity surface
emitting diode lasers and optical fiber amplifiers.
15

Background Of The invention

Single mode optical fibers doped with rare-earth
elements are well known for their high efficiency.
20 However, lasers made with doped fibers as gain medium
bear challenges in cavity stabilization. Usually a

sophisticated and complex scheme has to be employed in order to obtain a stable and high quality spectral output. A vertical cavity surface emitting laser (VCSEL) with a movable mirror has the advantage of providing a wide tuning range with high quality spectral output, but the efficiency of the VCSEL tends to be limited due to low gain of the cavity. The maximum possible power from an optically pumped VCSEL is further restricted by the difficulty of dissipating heat, which tends to limit full use of the increasingly high power available from single mode pump diodes.

Summary Of The Invention

The primary object of the invention is to provide an efficient, high power and high quality tunable laser source.

A further object is to extend the capabilities of optically pumped tunable vertical cavity surface emitting diode lasers.

Still another object is utilize a doped fiber amplifier to increase the power output of an optically pumped VCSEL.

5 These and other objects are achieved by providing
a laser source that comprises in combination a VSCEL,
a doped optical gain fiber, a pump laser, and means
coupling said pump laser, said VCSEL and said fiber
whereby said VCSEL and said fiber are optically pumped
by the output of said pump laser and the output of
10 said vertical cavity surface emitting laser is
injected into said fiber and is amplified in said
fiber by the output of said pump laser. Other
features and advantages of the invention will be made
clear by the following detailed description which is
15 to be considered together with the accompanying
drawings.

The Drawings

20 Figure 1 illustrates an amplified tunable VCSEL
constituting a first and preferred embodiment of the
invention;

Figure 2 illustrates a second embodiment of the invention;

Figure 3 illustrates a third embodiment of the invention; and

5 Figure 4 illustrates a fourth embodiment of the invention.

In the drawings, like components are identified by like numerals.

10 A Specific Description Of The Invention

15 The several embodiments hereinafter described combine the advantages of a VCSEL with the advantages of doped optical gain fibers, thereby providing economical, efficient, high power and high quality tunable laser sources.

20 Referring now to Figure 1, the illustrated apparatus comprises a pump laser 2 which emits a spatial single mode beam 4 at a wavelength λ_1 . That beam is preferably collimated by a lens 8 and passes an optical isolator 6. The latter directs beam 4 at a diachronic beam splitter 10 which effectively

subdivides the beam power, with part of beam 4 being reflected as a beam 12 with wavelength λ_1 and the remainder of beam 4 passing through the beam splitter as laser beam 14 with wavelength λ_1 . The beam 12 is directed by the beam splitter 10 into a VCSEL represented schematically at 16. Various forms of VCSELs may be used in practicing this invention. Preferably the VCSEL has a structure like one of those described in co-pending U.S. Patent Application No. 09/281,407, filed March 30, 1999 by Daryoosh Vakhahoori et al. for "Optically Pumped Tunable Surface Emitting Lasers", and U. S. Patent Application No. 09/105,399, filed June 26, 1998 by Tayebati et al. for "Microelectromechanically Tunable, Confocal, Vertical Cavity Surface Emitting Laser and Fabry-Perot Filter", which applications are incorporated herein by reference. Still other forms of VCSELs known to persons skilled in the art may be used in practicing the invention.

The VCSEL 16 has a fixed mirror 18 and a movable cavity mirror 20 at opposite ends of a cavity 21, plus

electrodes (not shown) for electrically tuning the device. In the VCSEL, wavelength tuning is achieved by moving mirror 20 so as to vary the laser cavity length. In Fig. 1, beam splitter 10 is located along the optical axis of the VCSEL as shown, so as to maximize the optical coupling of beam 12 with the VCSEL and avoid the need for intervening optics. The pump laser beam 12 at wavelength λ_1 passes into the cavity via mirror 20 to optically pump the VCSEL and cause the latter to produce an output beam 24 at wavelength λ_2 that exits via mirror 20. The splitter 10 is designed and disposed so that it will pass VCSEL laser beam 24, while at the same time splitting pump laser beam 4 as described. In this connection, it is to be noted that the VCSEL output beam 24 is polarized as a result of well controlled birefringence of the VCSEL. The VCSEL laser output beam 24 passes from splitter 10 via an optical isolator 26 into a polarization dependent high reflector/beam splitter represented schematically at 28 which is interposed between a diachronic mirror 30 and an output focusing

lens 32. Splitter 28 is adapted to reflect the polarized VCSEL beam 24 to mirror 30. The latter is adapted to pass VCSEL beam 24 to a focusing lens 38 and also to reflect pump laser beam 14 as hereinafter described.

The laser apparatus of Fig. 1 further includes a highly reflective mirror 34 which is disposed to receive λ_1 wavelength beam 14 and to reflect it to diachronic mirror 30. The latter in turn reflects beam 14 to focusing lens 38. The latter transmits VCSEL beam 24 and pump laser beam 14 into one end of a doped high gain optical fiber 40. The opposite end of the fiber is coupled to a Faraday rotator mirror 42 which reflects the VCSEL beam back along the fiber toward beam splitter 28 and also serves to rotate the VCSEL beam polarization 90 degrees so that it can pass through beam splitter 28 to output lens 32.

Operation of the laser system of Fig. 1 is as follows. The VCSEL 16 responds to the pump laser beam 12 at wavelength λ_1 by generating VCSEL laser beam 24 at wavelength λ_2 . The VCSEL laser beam passes through

the beam splitter 10 and isolator 26 to beam splitter 28, which then reflects the beam to diachronic mirror 30. The VCSEL beam passes through mirror 30 and is transmitted by the focusing lens 38 into the high gain fiber 40. The pump laser is chosen with an output beam wavelength λ_1 that will effectively pump the doped gain fiber 40, which typically has a relatively narrow absorption band. In this connection it is to be noted that the VCSEL, being made from a semiconductor, has a wide tolerance for the wavelength of the pump laser in relation to its response to the pump laser beam.

The illustrated apparatus of Fig. 1 experiences maximum amplification due to the fact that the laser beam output of the VCSEL essentially has a double transit along the length of high gain fiber 40. As noted above, the VCSEL beam 24 has a selected polarization as it passes from splitter 10 that allows it to be reflected by beam splitter 28. However, the Faraday rotator mirror 42 rotates the polarization of the VCSEL output beam 90 degrees, with the result that on its return transit along gain fiber 40 the beam

passes through splitter 28 and is extracted from the system by passing through output focusing lens 32 to an output port. By way of example but not limitation, the output port may comprise an optical fiber 50.

5 Figure 2 illustrates an alternative embodiment of the invention. In this arrangement, the beam splitter 28 is omitted and the VCSEL output beam 24 passes directly to diachronic mirror 30. Beam 24 passes through mirror 30 to focusing lens 38. Additionally
10 a highly reflective mirror 52 is positioned to reflect pump laser beam 14 received from mirror 34 and to direct it to diachronic mirror 30 which is positioned so as to reflect beam 14 to focusing lens 38. The
15 latter directs the combined beams 14 and 24 into one end of a single mode high gain fiber 40A which also serves as the output line.

Operation of the embodiment of Figure 2 is as follows. The VCSEL output beam 24 at wavelength λ_2 is transmitted via the isolator 26 to diachronic mirror
20 30 which passes it into the high gain fiber 40A. Simultaneously the pump laser beam 14 at a wavelength

λ_1 is injected into the high gain fiber via reflections by mirrors 34, 52 and 30 to provide amplification for the VCSEL output beam. As a result the λ_2 wavelength output beam that exits the remote end of the high gain fiber line 40A has a greater power than the original output beam of the VCSEL.

Figure 3 illustrates still another embodiment of the invention. In this case pump laser 2, a collimating lens 8A, isolator 6 and diachronic beam splitter 10 are disposed so as to optically pump the VCSEL 16 via transit through its fixed mirror 18. Beam splitter 10 splits the λ_1 wavelength pump laser beam 4 into beams 12 and 14. The pump laser beam 14 is injected into the VCSEL via the stationary mirror 18, causing the VCSEL to produce a laser output beam 24 with wavelength λ_2 . That beam passes through diachronic mirror 30 to a focusing lens 38 which couples the beam into one end of single mode optical gain fiber 40A which also serves as the output line. The system of Fig. 3 also includes mirrors 34 and 52 which are arranged to intercept, reflect and direct

pump laser beam 12 to the diachronic chronic mirror 30 at an angle such that it will be reflected to focusing lens 38 and directed thereby into the proximal end of gain fiber 40A. Pump laser beam 12 acts on high gain fiber 40A to amplify the power of the VCSEL beam injected into fiber 40A.

Figure 4 shows a fourth embodiment of the invention. In this case a single mode high gain fiber 40B is coupled at one end to an external wavelength division multiplexer 56. The near end of the fiber 40B is disposed so as to be optically coupled to VCSEL 16, whereby (a) the VCSEL may be pumped by a pump laser beam as hereinafter described and (b) the λ_2 wavelength output beam of the VCSEL is injected into the near end of the gain fiber. The manner in which the fiber 40B is optically coupled for injection therein of the laser output of the VCSEL is not critical to the invention; therefore, optical coupling of fiber 40B to the VCSEL may be accomplished in various ways known to persons skilled in the art without departing from the invention. A pump laser 2

is provided for producing a pump laser beam at wavelength λ_1 , and injection of that pump laser beam into fiber 40B is accomplished via a wavelength division multiplexer 56 which is coupled to the outer end of gain fiber 40B. The exact form of the multiplexer is not critical to the invention and various forms of multiplexers known to persons skilled in the art may be used in practicing the embodiment shown in Figure 4. The multiplexer serves several purposes. It injects the pump laser beam 4 into the high gain fiber 40B, whereby to provide amplification for the VCSEL's laser output. It also serves as the system's output port for the VCSEL's amplified laser beam, whereby that beam may be coupled to another device or system, e.g., via an optical fiber 60.

Operation of the system of Figure 4 is as follows. The pump laser 2 injects a pump laser beam with a selected wavelength λ_1 into fiber 40B via the multiplexer 56. The injected pump laser beam is injected via the fiber into the VCSEL, causing the latter to generate a laser output at a wavelength λ_2

which then travels along the fiber to the output port of the multiplexer. As the output from the VCSEL travels to the multiplexer, it is amplified by the counter-propagating pump beam in the gain fiber.

5 Consequently the power level of the VCSEL output appearing at the output port of the multiplexer 56 is substantially greater than that of the VCSEL beam that is injected into the near end of the fiber. The amplified VCSEL beam that exits the output port of the
10 multiplexer 56 may be coupled to an external optical system for use, e.g., to an optical communications network.

15 The configuration of Figure 4 offers the advantage of simplicity and high amplification relative to the co-propagating configuration of Figures 2 and 3. The maximum amplification of the embodiment of Figure 4 is restricted by the feedback between the VCSEL and the wavelength division
20 multiplexer, which must be kept very low to prevent lasing from the fiber amplifier.

The invention hereinabove described and illustrated offers the advantage of providing an efficient tunable laser source combined with the advantages of a VCSEL and a fiber amplifier, with the result that laser sources as provided by this invention have utility in optical data and communication equipment and networks.

The present invention may also be practiced otherwise than as herein described and illustrated. For example, use of the optical isolators 6 and 26, which serve to suppress optical interference between the components, is preferred but is not essential to the invention. Additionally the optics coupling the VCSEL laser, pump laser and high gain fiber may be varied in various ways without departing from the essence of the invention. It is understood also that the pump lasers with outputs of different wavelengths values may be used in practicing the invention, provided, however, that they are suitable for adequately optically pumping the VCSELs. The injection of the pump beam of wavelength λ_1 to the

VCSEL and the output of the VCSEL at wavelength λ_2 may be coupled via various forms depending on the design of the cavity mirrors.

5 The invention is susceptible of still other modifications that will be obvious to persons skilled in the art from the foregoing description and the drawings.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217